N63-14588

NASA TN D-1769

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TECHNICAL NOTE

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AN INVESTIGATION OF FLOW VISUALIZATION TECHNIQUES IN HELIUM AT MACH NUMBERS OF 15 AND 20

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON April 1963

554162

28p

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AN INVESTIGATION OF FLOW VISUALIZATION TECHNIQUES IN HELIUM AT MACH NUMBERS OF 15 AND 20

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SUMMARY

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This report presents an investigation which adapted the techniques developed for subsonic and supersonic flow visualization to a helium tunnel operating at Mach numbers of 15 and 20. Three techniques are discussed:

1. The fluorescent-oil film technique for making surface streamlines visible and for locating flow separation on a test body

2. The white-lead technique for locating the stagnation point and and streamlines radiating from the stagnation point on a test body face at various angles of attack

3. The ionization technique for making visible the regions of flow separation and attachment on afterbodies.

Results indicate that surface streamlines, stagnation points, and separated and attached flow over an afterbody may be made visible on a variety of test body configurations in hypervelocity helium flow.

INTRODUCTION

The value of schlieren and shadowgraph techniques for visualizing the features of subsonic and supersonic flows over a body has been proven by their continued use over the years. In wind tunnels that operate at very high Mach numbers or very low Reynolds numbers, however, the density of the stream in the test section is reduced to such an extent that such techniques may be unable to do much more than define the bow shock wave, and this possibly only for a blunt body. For this reason, it is necessary to utilize additional techniques if other features of the flow are to be visualized.

The purpose of this investigation was to adapt or modify existing visualization techniques for use in a helium tunnel at Mach numbers of 15 and 20. Three techniques were investigated: the fluorescent-oil film, the white-lead, and the ionization techniques. The fluorescent-oil film and white-lead techniques have been used by a number of investigators in the past to study surface streamlines and indications of flow separation and reattachment. Some applications of these techniques, and related studies, are reported in references 1 through 5. The ionization technique has, in the past, been applied in two ways: a glow discharge method, which uses the direct illumination from an electrical discharge in the flow field, and an afterglow technique. This latter method makes use of the luminescence that remains in gases for some time after electrical excitation. References 6, 7, and 8 deal with studies conducted using such techniques. The present study utilized only the glow discharge method because of the short afterglow lifetime in helium.

The applications developed from this investigation are significant in that satisfactory flow visualization photographs proved to be obtainable in low-density hypersonic helium flow. All three techniques require little in the way of sophisticated equipment or procedures, and their applications lend themselves readily to almost any wind tunnel.

EQUIPMENT

Test Facility

The tests were conducted in the blowdown type helium tunnel illustrated in figure 1. Interchangeable nozzles provide a choice of either Mach number 15 or 20 and runs of 20 to 30 seconds duration may be made at both Mach numbers. The test section of this tunnel, shown sketched in figure 2, is 48.0 inches long and 19.5 inches in diameter at the model station. The ratio of free stream to total density in helium is 0.001509 at Mach number 15 and 0.0006423 at Mach number 20.

Test Bodies

Five test-body configurations were used in the investigations. A sketch of these test bodies is presented in figure 3. Bodies A and E have conical afterbodies and spherical faces; body B is cylindrical with a blunt serrated nose followed by a conical section, and flared afterbody; body C is a truncated cone with flaps on the base of largest diameter; body D is a delta-winged glider configuration.

Photographic Equipment

A 16 mm motion picture camera, fitted with a 25 mm focal length lens, and a 35 mm still camera were used in photographing the flow patterns in the visualization tests. Since the patterns in both the fluorescent-oil film and ionization techniques required a period of time to develop and were lost when flow was stopped, motion pictures were obtained of the pattern development and stabilization. The region of primary interest in the white-lead technique was the face of the test body, and it was impossible to position the motion picture camera for a head-on view. Still photographs were taken after each test. Since the stagnation point and streamlines were preserved intact after the tunnel was shut down, there was sufficient time to remove the model from the tunnel. The film types and camera settings were different for each technique and are, therefore, mentioned separately under Procedures.

PROCEDURES

Fluorescent-Oil Film Technique

The undesirable high vapor pressure characteristics of standard oils at the very low test pressures made it necessary to use vacuum-pump oil for these studies. An ultraviolet additive powder, Blak-Ray No. DF-502 oil-soluble fluorescent dye, was mixed with the oil in the ratio of one part by volume of powder to three parts oil. This was an arbitrary ratio, but increasing the amount of powder added little to the fluorescence of the oil and affected the viscosity only slightly. Various gear oils and greases were substituted for vacuum-pump oil but the conclusion was that oils or greases heavy enough to have slow evaporation rates in a near vacuum were too viscous to form flow patterns.

To obtain the maximum intensity and contrast for photography, the fluorescent-oil film on the test body had to be uniformly illuminated with ultraviolet light by the equipment illustrated in figure 4. The windows on both sides of the test section were fitted with BH-6 mercury-vapor lamps. Forced-air cooling lines were installed between the lamps and the windows to protect the latter from heat generated by the lamps. Type 754 filters were fitted on each lamp to minimize the visible background light. The access port on top of the test section was fitted with a 1/2-inch-thick quartz window. Quartz was used because of its transmissivity of ultraviolet light. An H-100 FL-4 projector flood lamp, rather than a mercury-vapor lamp, was mounted in the top window because of the limited space available. A type 754 ultraviolet filter was also used with this lamp. The camera is not shown in figure 4 because its position depends on the desired view of the test body. Camera settings of F4 at 8 frames per second were used with 16 mm daylight motion picture film. Later in this series of tests, the settings were changed to F2.7 at 24 frames per second to provide more film footage of the pattern development.

Surfaces of the test bodies in the fluorescent-oil film studies were polished to enhance the definition of the streamlines and the ripples in the oil. Experiments reported in reference 1 proved that photographs of bodies with black or dull surfaces did not show sufficient contrast, whereas shiny surfaces reflected the ultraviolet light back through the oil and essentially doubled the intensity of the illumination.

Just prior to a run, the test body was mounted in the tunnel and all extraneous grease, oil, and dust particles were removed. The test body was covered with a thin film of fluorescent oil. An additional indicator of streamlines was finely powdered lead graphite applied in dots or a line just upstream of the area on the test body surface to be studied. Another thin coat of fluorescent oil was applied to suspend the graphite and give it greater mobility. The desired effect was for the attached flow to sweep the graphite and oil in distinct streamlines back over the area to be observed. The oil forms a ripple or wave at points of flow separation from the test body.

White-Lead Technique

The white-lead technique uses white lead as an indicator in the oil film rather than fluorescent dye or graphite. White lead is useful for the visualization of stagnation point and streamline locations on test body faces because the resulting pattern can be preserved long enough after cessation of flow to allow the test body to be removed from the tunnel and photographed. Other types of pastes and powders were tried, with vacuum-pump oil as the vehicle, but results from these mixtures were unsatisfactory in that patterns either failed to develop or were blown away before the tunnel was stopped. Commercially available white lead contains linseed oil, which had to be removed because of its undesirable high vapor-pressure characteristic. The white-lead linseed-oil mixture was diluted with acetone and strained repeatedly through filter paper leaving a dry, white paste of lead peroxide. The white-lead paste was mixed with vacuum-pump oil at a ratio by volume of one part white lead to four parts vacuum-pump oil. This ratio was dictated largely by the desire to keep the viscosity of the mixture nearly the same as that of the vacuum-pump oil. This mixture was found to be suitable for the pressures, Mach numbers, and duration of runs used in this investigation.

The portion of the test body to be studied was painted with one coat of zinc chromate primer and one coat of flat black paint to contrast better with the white lead. The coating of paint was applied as thinly and evenly as possible to avoid surface roughness.

The test body was mounted in the tunnel and a very thin film of white-lead mixture was applied to the region of interest. A thin film was found to provide better uniformity and less mobility to the pattern than a thick film.

To preserve the pattern on the face of the test body during shutdown of the tunnel, a cone was fitted on the downstream end of the starting probe. (See fig. 2.) The cone had the same maximum diameter as the test body, and was alined directly in front of the body when the probe was in the down position. At the beginning of a run, after flow had been achieved, the probe was raised out of the stream, exposing the face of the test body to the flow. At the end of the run, the probe was lowered prior to shutdown, thus protecting the white-lead pattern on the face of the test body.

Ionization Technique

Two approaches to the ionization technique are the afterglow method and the glow discharge method. Experiments outlined in reference 8, in which afterglow studies were conducted in several different gases, indicated that such tests were not successful in helium because the afterglow would not last a sufficient length of time to reach the test section. Therefore, the glow discharge approach was used in the present tests. This approach was difficult, however, because of the high ionization potential of helium.

The test-section arrangement for the ionization studies is illustrated in figure 5. The port directly above the test body was fitted with a plug made of Micarta for insulation. A copper rod was mounted off-center in this plug so that by rotating the plug 180° the rod could be positioned either ahead of or behind the test body. The rod itself was insulated with a plastic insulating tubing that could be shrunk to a tight fit by heating. Since voltages ranging from 1000 to 7000 dc were to be used in very low helium pressures during the tests, it was decided for safety reasons not to mount the test body on the regular model-support strut located in the test section. Such a mount would require running the high-voltage electrical cable through the near-vacuum of the test section, close to unshielded metal structures. The uncertainty of the performance of high-voltage cable insulation under such conditions dictated the design of a sting that could be mounted in one of the access ports. In this way, the high-voltage cable could remain outside the test section, and be connected to the test body by a brass or copper rod running through the sting in the access port. This rod was insulated in the same manner as the discharge electrode mounted on top of the test section.

The high-voltage negative lead was attached to the test body, making it the cathode, and the positive lead was attached to the discharge electrode, making it the anode. By this arrangement, it was possible to locate the discharge electrode well behind and above the test body, out of the immediate flow field. The flow itself would assist the discharge by carrying ions to the discharge electrode.

The test body was machined out of solid brass. Aluminum or copper would have given equal or better conduction, but would also scratch or scar more readily. The attachment of the test body to the sting was designed so that the body could be supported at selected angles of attack. During the tests, it was desired that the illumination of the gas originate around the forward portion of the test body and be swept back around the afterbody. Accordingly, the afterbody was coated with a flat black paint having an acrylic base to inhibit arcing from this region to the discharge electrode. The forward portion or face of the test body was left unpainted.

These tests were photographed with 16 mm daylight motion picture film, with camera settings of F1.9 at 24 frames per second. The test section was completely dark for this series of tests, so that the only light seen by the camera was that emitted by the ionization of the gas. The window opposite the camera was covered with black cardboard, and a black enclosure was made for the camera and operator at the other window.

Other arrangements tried, included the reversing of electrical leads to make the rod in the top of the test section the high-voltage electrode, or anode, and the test body the discharge electrode, or cathode. Experiments proved that in order to sustain a glow discharge in the region of the test body while the tunnel was operating, the anode had to be within an inch of the test body. To obtain sufficiently intense ionization about the test body for photography, the anode had to be within 1/2 inch of the forward corner of the test body. This location interferred with the shock wave and flow field in general.

RESULTS AND DISCUSSION

Fluorescent-Oil Film Technique

Flow patterns obtained by the fluorescent-oil film technique on the surfaces of four different test bodies are presented in figure 6. Body A is shown with the top of the afterbody parallel to flow. The oil and graphite have been swept back along the afterbody from the forward corner, and a distinct ripple in the oil, believed to indicate the line of flow separation, has formed about halfway down the side of the afterbody. The upward trend in the forward end of the separation line near the corner is believed to be caused by the vortex action of reversed flow. This print is from one frame of a motion picture which showed oil on the bottom, or leeward side of the afterbody being swept forward and up, in the direction opposite to the free-stream flow.

Body configuration B was mounted at a small angle of attack and photographed from a quarter front view. Streamlines apparent in the photograph indicate that the flow travels back and over the cylindrical portion of the test body, and a collection of oil at the top of the flare indicates that the flow has apparently separated in this region.

Body configuration C was mounted at a small angle of attack, and rotated about its roll axis so that the top and flap were presented to the camera. Streamlines are plainly visible in the oil indicating a flow which sweeps back and around the body, forming what is believed to be a separation line ahead of and around the flap. A region of reversed flow is believed to be indicated by the streamlines appearing between the flap and the separation line.

Body configuration D was mounted at a small angle of attack, and was rotated about its longitudinal axis so that the top was visible to the camera. Streamlines may be seen on the nose, fuselage, and fins, and there is no indication of separated flow over these surfaces. (The differences in colors between the photographs in figure 6 are due to differences in test-body materials.)

The vacuum-pump oil had fairly low viscosity, even with the fluorescent dye added, and it flowed easily, though slowly, on the sloping surfaces of the test bodies. This was undesirable in that precisely located dots or lines of graphite would tend to flow with the oil before the tunnel was started, leaving insufficient amounts of graphite upstream of the region to be studied. To alleviate this problem, the graphite was applied in small dots, rather than a line, and the second coat of fluorescent oil was limited to the area immediately upstream of the graphite. In this way, any motion of the second coating of oil prior to the starting of the tunnel would not affect the graphite. When the tunnel was started, the oil was swept downstream, picking up the graphite as it moved back along the test-body surface.

The photographs taken during the tests proved that the fluorescent-oil film with finely powdered lead graphite indicated the streamlines and separation lines satisfactorily for observing and photographing surface-flow patterns on a variety of test body configurations. Attempts to use this method of visualization on test-body faces proved unsatisfactory in that the oil, and graphite when used, were completely swept away in the region of the stagnation point.

White-Lead Technique

Flow patterns formed on the face of test body A at various angles of attack with the white-lead technique are presented in figure 7. The top photograph shows the flow pattern formed when test body A was at 0° angle of attack. The stagnation point may be seen in the center of the face, and the streamlines exhibit the radial symmetry of flow from the stagnation point outward to the corners. The pattern in the middle photograph resulted from pitching the test body to an angle of attack of 15°. The stagnation point has moved away from the center, and the streamlines are shown flowing toward the corners in a three-dimensional pattern. The lower photograph shows the pattern formed at an angle of attack of 33°, with the stagnation point appearing at the most windward portion of the face.

Results similar to these shown in the photographs were obtained consistently on similar forebody configurations, and provided visual data upon which to base the location of future heat transfer and pressure measuring instrumentation.

This method was tried on several afterbodies, but satisfactory patterns were not formed, even though the viscosity of the oil was essentially the same as in the fluorescent-oil film technique. Apparently the lead peroxide paste was not as mobile as the lead graphite in vacuum-pump oil. Thus, when the oil was swept by attached flow, the lead peroxide paste would either not move, or would move without leaving a streamline.

Ionization Technique

Characteristics of the flow over the afterportion of test body E, as indicated by the ionization technique, are shown in figure 8 for various angles of attack and for a free-stream Mach number of 15.

The discharge electrode is above and behind the test body, and is out of the line of sight of the camera. The spots of light on the afterbody are believed to be a corona effect, or "hotspots," caused by arcing through the thin paint layer. A thicker coat of acrylic-base paint would eliminate this phenomenon.

The ionized gas is shown being swept back from the corners of the forebody, forming an envelope of illuminated flow around the afterbody. The illuminated regions around the body are believed to indicate separated flow. The lower photograph, showing the illuminated gas contacting the afterbody, is believed to indicate flow reattachment. These hypothetical indications were later substantiated by pressure and heat-transfer data taken on a model similar to test body E at the same angles of attack.

CONCLUDING REMARKS

The three techniques described in this paper appear to be useful and efficient for visualizing flow in helium at Mach numbers of 15 and 20. Surface streamlines and flow separation lines on various afterbody configurations could be seen with the fluorescent-oil technique; the white-lead technique made the stagnation points and streamlines distinct on the spherical face of a test body at different angles of attack; and the glow discharge ionization technique illuminated the envelope of gas flowing about a test body so that the separated and attached flow could be observed.

These techniques may be employed in almost any tunnel of moderate size without extensive modifications to the relatively simple equipment described in this report. The ease with which this equipment may be set up and put into operation make preliminary flow visualization studies a logical and practical prelude to heat-transfer or pressure distribution tests. The visual presentation of flow patterns on and about a model provides information for instrumenting models and planning future tests.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif., Jan. 17, 1963

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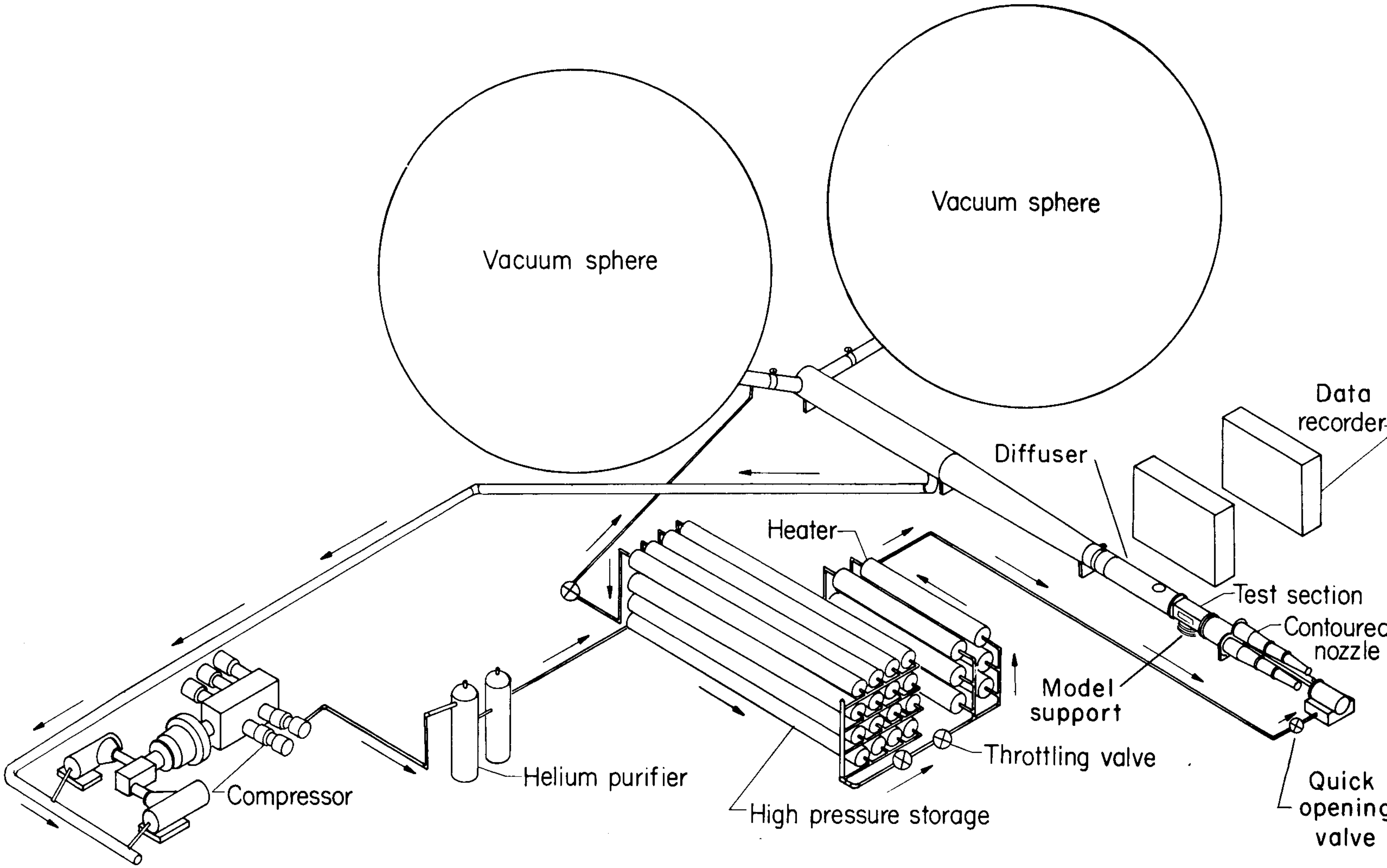

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Figure 1.- Diagram of hypersonic helium tunnel.

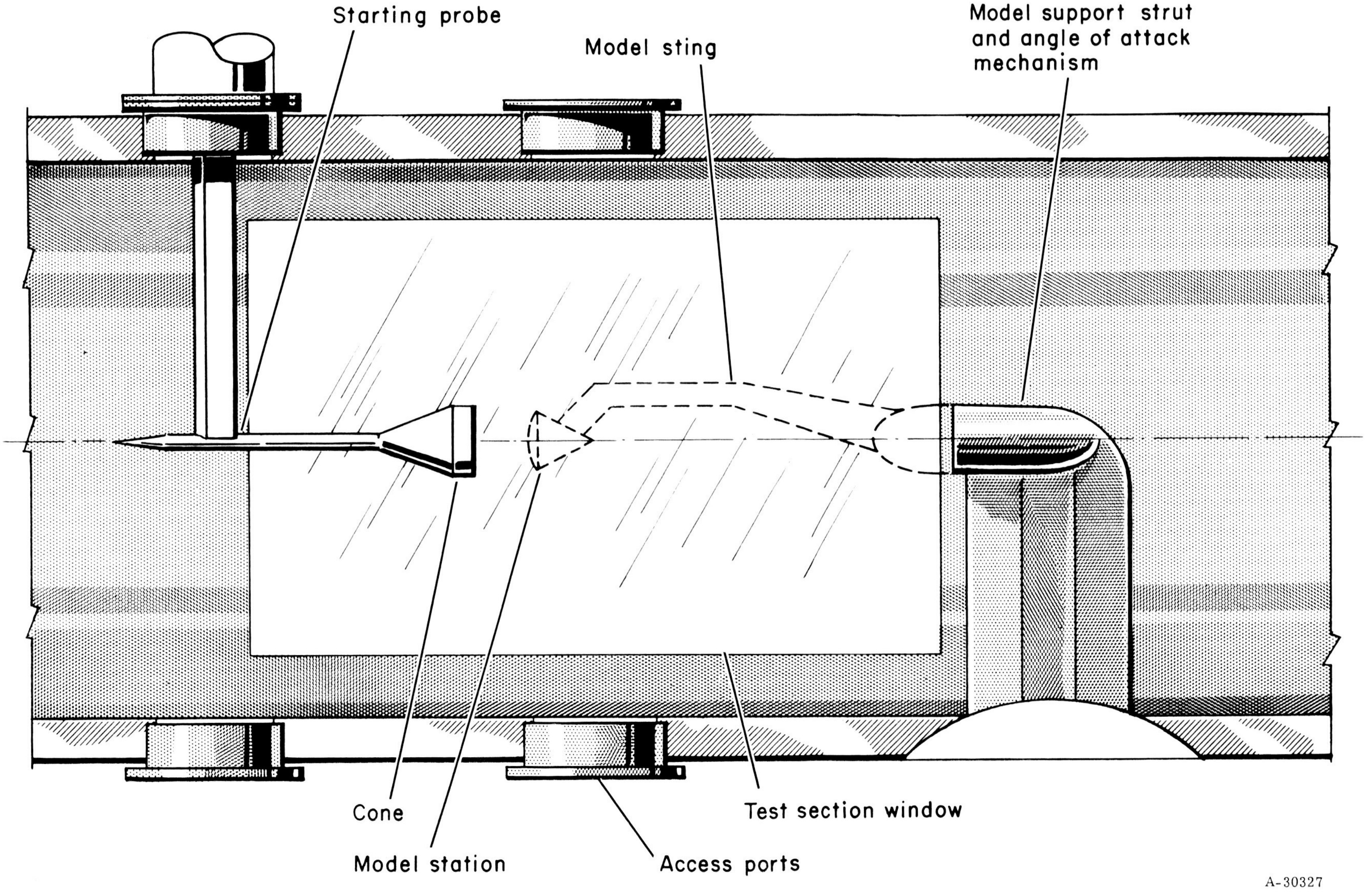


Figure 2.- Cross section view of test section.

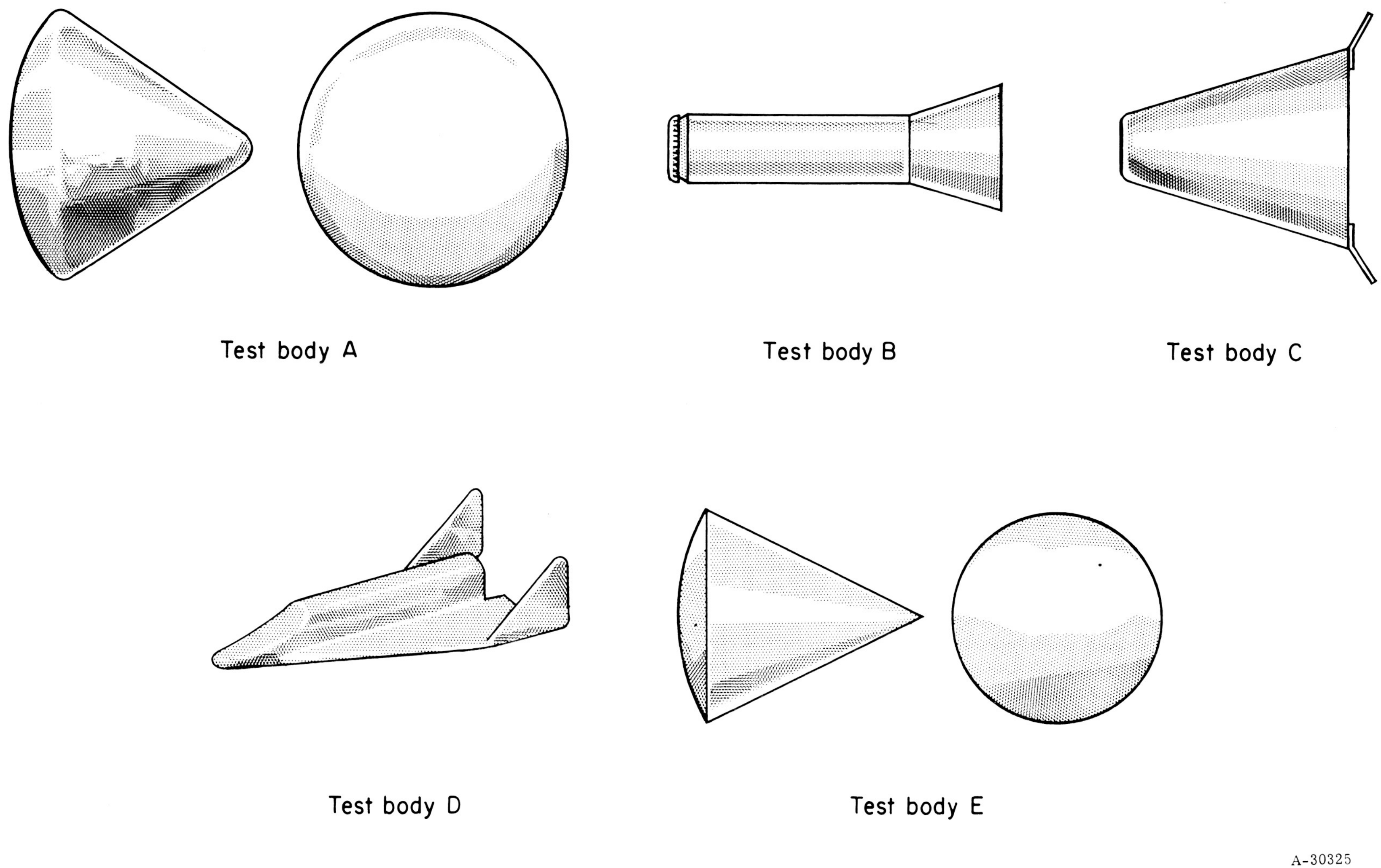


Figure 3.- Test body configurations.

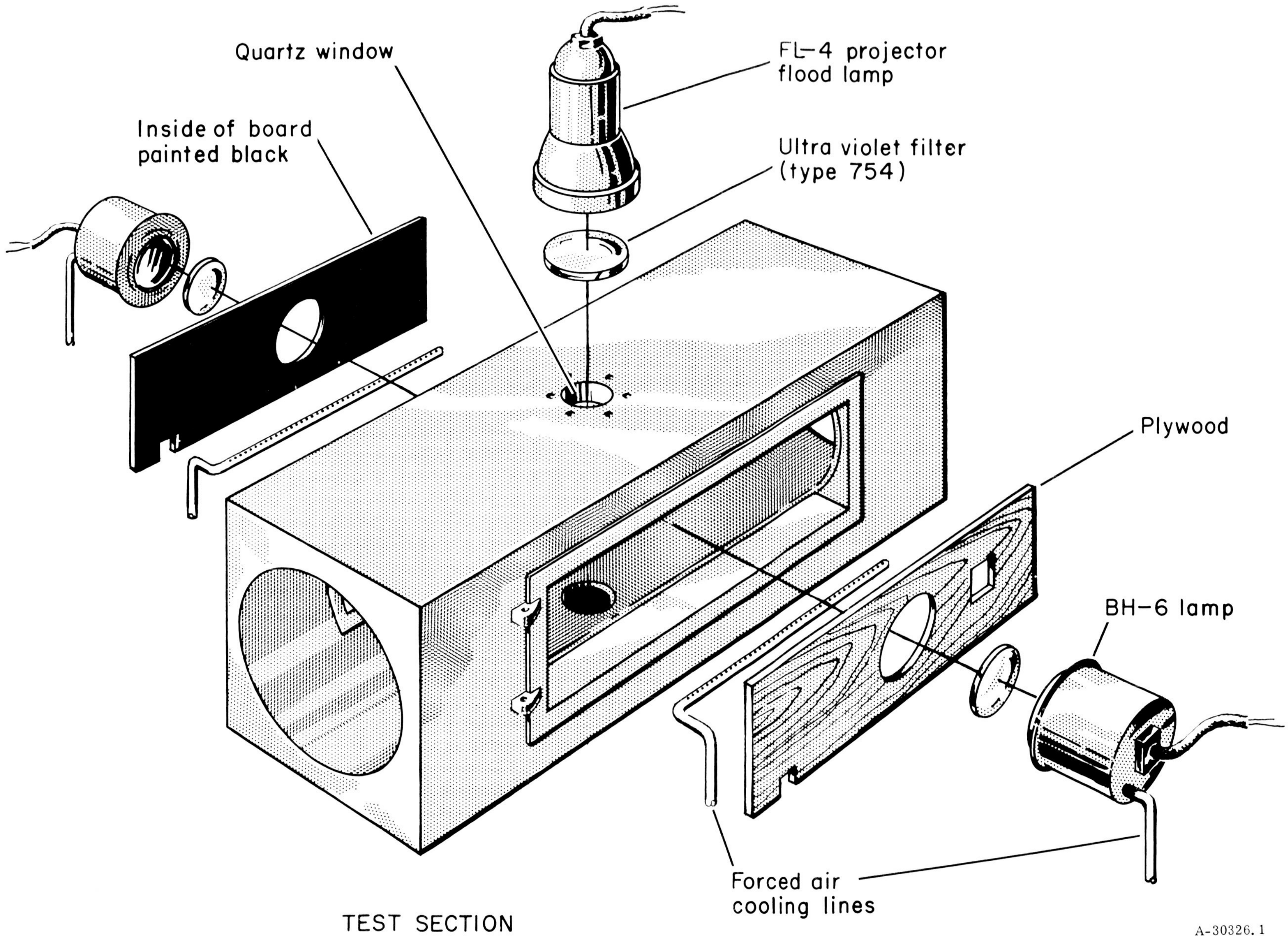


Figure 4.- Test section arrangement for fluorescent-oil film technique.

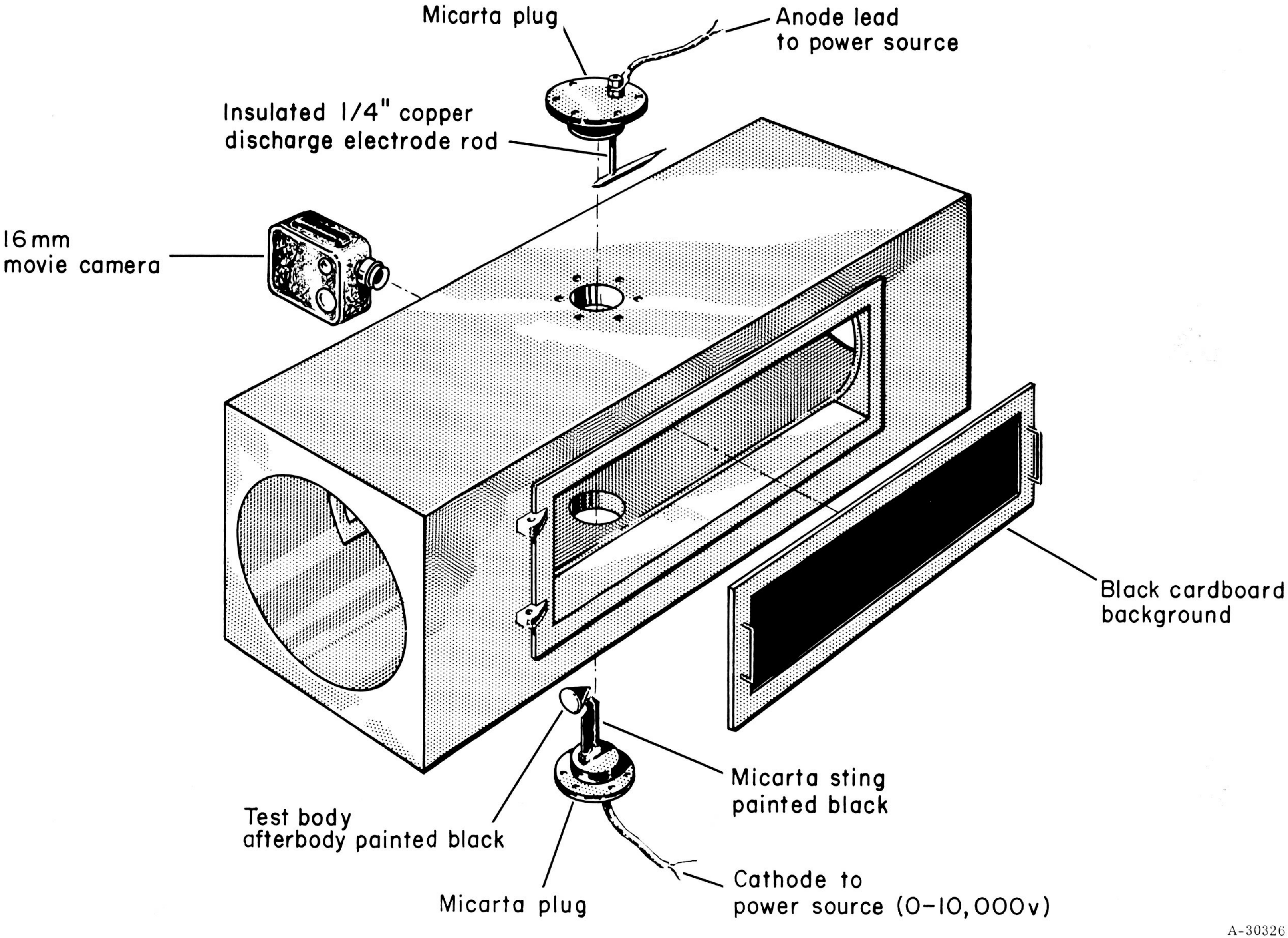
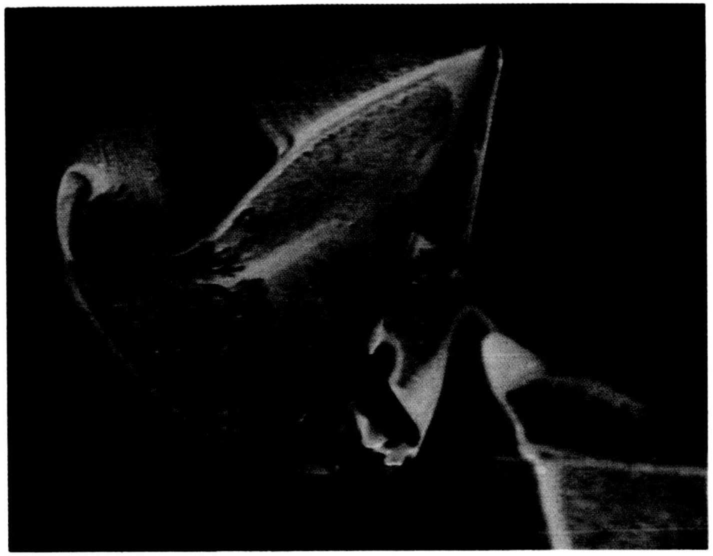
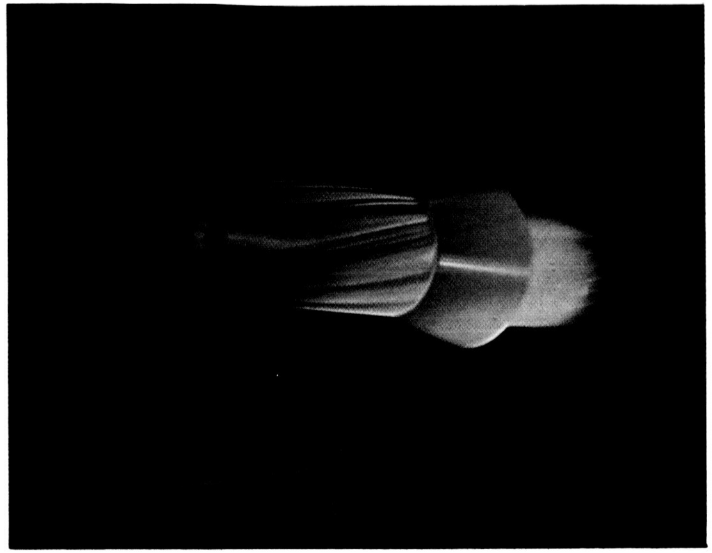


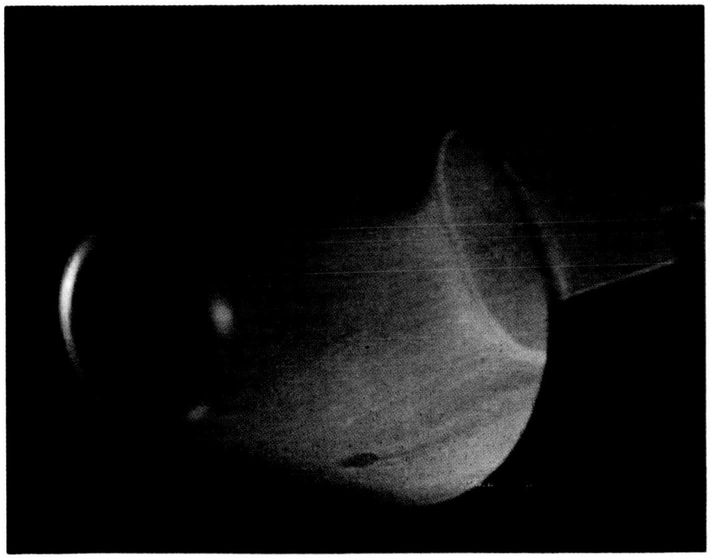
Figure 5.- Test section arrangement for ionization technique.



Test body A. A-29580



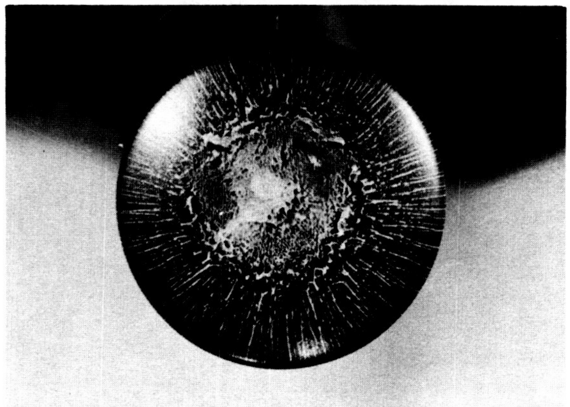
Test body B. A-30232



Test body C. A-30233

Test body D. A-30165-2

Figure 6.- Fluorescent-oil film technique; Mach number 20 in helium.



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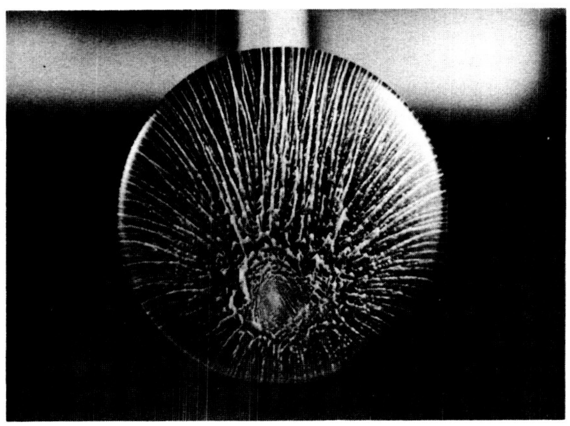

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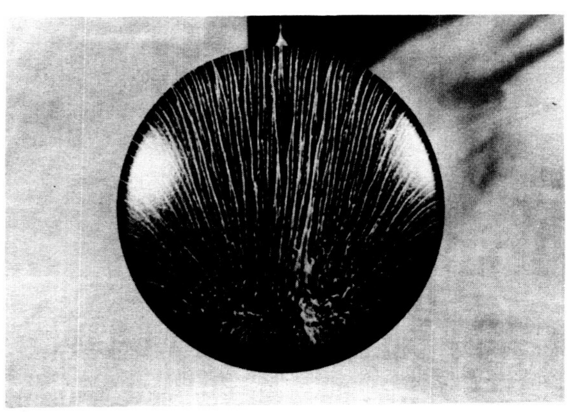
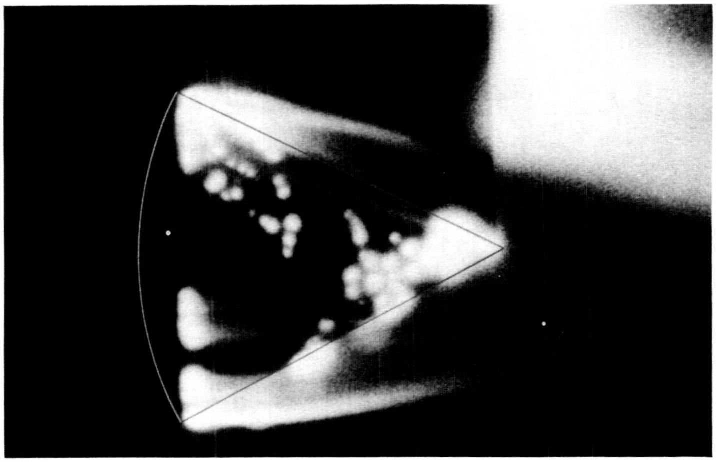


$\alpha = 33°$ A-30328

Figure 7.- White-lead techniques; Mach number 20 in helium; test body A.



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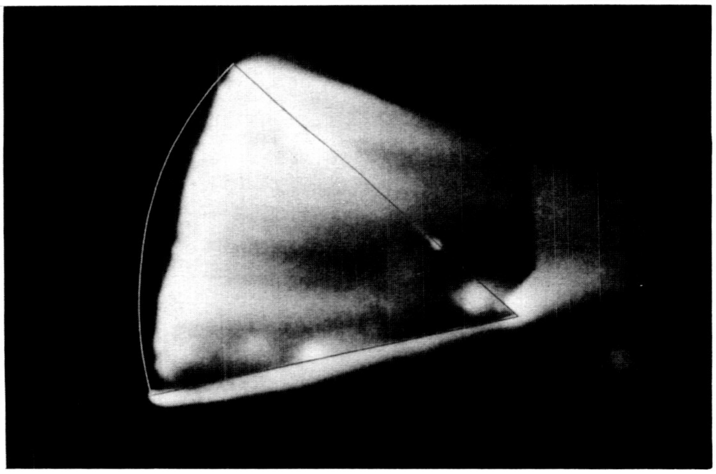

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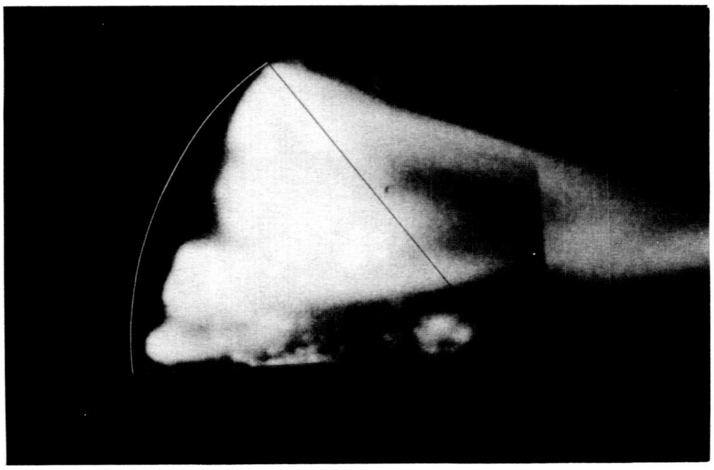

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Afterbody top
parallel to flow

$\alpha = 25^{\circ}$

Figure 8.- Ionization technique; test body E at Mach 15 in helium.

NASA-Langley, 1963 A-751